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Evaluation of Internal Ballistic Capabilities of Wave Gun for Tactical Weapons Application

Interim Report Number 1
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1. Introduction

The information presented in this report has been generated under Phase I of an SBIR contract that is funded by DARPA. The objective of the contract is completion of an evaluation of the limits of performance of the Wave Gun concept that is described in Reference 1. The evaluation is limited to tactical applications where the interest is in muzzle velocities up to about 3 km/sec, dictated by limits on projectile velocity to avoid melting or other forms of ablation of a passively cooled projectile (see Reference 2). Wave Gun is a two-stage-light-gas-gun, but employs a cycle differing radically from a conventional light gas gun. For the tactical arena, the second stage light gas being considered is helium.

The contract is limited to a theoretical evaluation of Wave Gun performance employing a computer code developed by Astron called AIBAL, a mnemonic for Astron Internal Ballistic Hydrocode. (The elements of the code are described in Reference 1.) The contract requires two interim reports and a final report. This report constitutes the first interim report. It is devoted to describing the modifications to the AIBAL algorithms preparatory to the execution of a matrix of calculations exploring the internal ballistic characteristics of generic Wave Gun.

2. Data processing modifications to AIBAL

AIBAL as described in Reference 1 is a series of computer codes that are exercised sequentually to generate a set of input data, act on the input to compute the internal ballistic characteristics, and then generate the output that is plotted for evaluation and presentation purposes. Since many calculations are required to meet the objectives of the contract, effort has been devoted on the front end to automate the operation to minimize the need for human intervention. The elements of the code and how they have been modified for the purposes of this contract are outlined below.

The algorithm starts with an input data generator that is written in BASIC. Menus are provided for all of the required input data, and the output is written to a file which serves as input to a FORTRAN based processor. Because of the differences between BASIC and FORTRAN conventions, manual editing of the input generator output file has been required in the past. The editing process has now been avoided.

A command file has been written that can sequentially read up to 9 processor input files, and execute AIBAL to completion between readings of files. Coding has been developed to summarize the processor input in convenient format that is output to a printer. Certain selected detailed output is routed to an output file during execution of AIBAL, but it is quite minimal to cut down on the amount of paper generated during the final output to the printer. The bulk of the output (the data that are to be output are specified in the input generator) is also written to the output file. When the last time step in a calculation is completed, another part of the command file screens the output data and picks out significant data such as the magnitudes and timing of peak pressures. These data are then printed out in convenient and compact format.

The command file also calls a routine that prints out the selected detailed data in the output file and sets up the formats for all of the output data that are to be plotted. The data are then automatically plotted using a dot matrix printer. Up to 50 plots per case can be handled with the current plotting software.

The indicated data processing modifications taken together allow generation of a batch of up to 9 sets of input, analysis and summary of the input and output, execution of the AIBAL algorithm, and output of the bulk of the desired data in printed and plotted forms, all without human intervention. All of the coding has been written for a Cromemco Z2D microcomputer. Currently, computational capability is being expanded to decrease the execution time by at least and order of magnitude, and to increase the number of zones that represent the internal elements of a Wave Gun. This is being done via rental of a Cromemco CS-2H microcomputer with a Motorola 68000 32 bit processor and 20 megabytes of hard disc storage. As a backup and to facilitate certain of the calculations, the coding has also been implemented on a Prime 750 minicomputer using an adaptation of the STEALTH (Reference 3) methodology.

3. AIBAL modeling improvements

Comparisons of early AIBAL calculations with experimental Wave Gun data are presented in Reference 1. The comparisons are quite favorable. However, the calculations required an empirical upward adjustment of published burning rate data to achieve the degree of correspondence that was reported. In addition, the timing of the pressure peaks at the entrance to the gun tube disagreed somewhat from the data, implying higher frequency oscillation of the piston than calculated. This was attributed in large part to significant erosive burning in the propellant during the first rebound of the piston, supported by measured pressures in the propellant chamber at that time in the cycle. Finally, the motion of the projectile was not in exact agreement between AIBAL and the experimental data although muzzle velocities were calculated quite accurately.

Since it is most desireable that the final results of this effort be realistic, a significant effort has been devoted to improving the AIBAL modeling to correct the noted deficiencies. Of first importance is the inclusion of erosive burning modeling. To this end, a technique was developed for estimating the differences between propellant grain and burned propellant gas velocities. Erosive burning modeling was added to the basic propellant burn rate relation to show an augmented burn rate linearly dependent on the difference between the gas and unburned propellant velocities.

Simultaneous adjustments of erosive burning coefficient and propellant drag coefficient were made to the input of several runs in an attempt to achieve better correspondence with the data. The parameters that we were trying to match between calculations and experiment included the magnitudes and timing of the first two peak pressures near the entrance to the gun tube, and the magnitudes and timing of the first and third peak pressures in the propellant chamber. The need for inclusion of a friction force on the piston became apparent after rather extensive calculations.

Piston friction is modeled based on radial forces acting on the piston due to the pressures acting on the front and rear of the piston, and a coefficient of friction that relates the radial force to the shear force. The force model is based on an elastic piston model. The results of the model show that the drag force depends on the average of front and rear pressures acting on the piston, the piston shear area, and the product of the coefficient of friction times the Poisson's ratio of the piston material.

Another series of calculations were then carried out, simultaneously adjusting three constants to obtain a match with the data. Quite excellent matches have been realized employing magnitudes of the constants that are well within reasonable bounds. Currently, published strand burning rate data are being used in the calculations, augmented by the erosive burning formulation.

In the area of projectile motion, two phenomena have been under investigation - projectile friction and projectile face pressure. The projectile friction model is the same as that of the piston. To evaluate the projectile face pressures, a series of AIBAL runs were executed modeling a constant acceleration projectile and the air column in the gun tube ahead of the projectile. It was found that the simple wave model reported in Reference 1 significantly overpredicts the magnitudes of projectile face pressures. On the other hand (and partly by coincidence) a model that calculates the pressure behind a normal shock with the gas behind the shock moving at projectile velocity does a very good job of estimating the projectile face pressures (a future technical note will probably be published on this, since this result also has utility for the EM gun community). Currently, we are executing a number of calculations to derive an empirical coefficient of friction for the projectile.

In summation of these modeling studies, erosive burning and piston friction models have been developed and implemented in AIBAL to show a significant improvement in the calculations relative to experimental data. Projectile friction is now considered and an improved model of projectile face pressure has been implemented.

4. Content of the next interim report.

The next interim report will include the results of the modeling and computer upgrade efforts by presenting the comparisons of revised predictions with experimental data. The report will also include a definition of the matrix of calculations that will be carried out in order to execute the parametric study necessary to the objectives of the contract (currently, we have cut the matrix down to 23,300 calculations - this will obviously need to be culled further).

References

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3. Hofmann, R.: "STEALTH - A Lagrange Explicit Finite-Difference Code for Solids, Structural, and Thermohydraulic Analysis", Science Applications, Incorporated, Report EPRI NP-260, August 1976

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